A METHOD AND AN APPARATUS FOR MEASURING AND INDICATING THE FLUID LEVEL IN A CONTAINER

Patent Number:	WO9627120
Publication date:	1996-09-06
Inventor(s):	CHRISTIANSEN TOM (DK)
Applicant(s)::	UNITOR DENMARK AS (DK); CHRISTIANSEN TOM (DK)
Requested Patent:	☐ WO9627120
Application Number:	WO1996DK00089 19960301
Priority Number(s):	DK19950000210 19950301
IPC Classification:	G01F23/296 ; F17C13/02
EC Classification:	G01F23/296, F17C13/02H, G01F23/296F, G01F23/296T
Equivalents:	AU4784296, DK21095

Abstract

A method and an apparatus for measuring and indicating the fluid level in a container comprising at least two ultrasonic transducers (11, 12) arranged on the outer side of the container and preferably along a horizontal path. The transducers (11, 12) can be up and downwardly displaced. According to the invention, the distance between the transducers (11, 12) is substantially a number of half wavelengths, the ratio of the signals received at various times by the receiving transducer being used as a measurement of how much the sound has been attenuated during the transmission. In this manner the coupling losses are compensated for.

Description

Title: A method and an apparatus for measuring and indicating the fluid level in a container.

Technical Field.

The invention relates to a method of measuring and indicating the fluid level in a preferably cylindrical container comprising at least two ultrasonic transducers, which are arranged on the outer side of said container and preferably along a horizontal path, and which furthermore can be displaced up and downwards.

Backaround Art
Norwegian printed accepted specification No. 149,331 discloses an apparatus for measuring the fluid level in a container, for instance by means of ultrasonic transducers arranged on the outside of the container and being displaceable up and downwards relative to the container. The transducers are arranged diametrically opposite one another and are adapted to measure the transmission properties depending on the position of said transducers relative to the fluid level. Based on the changes in the transmission the up or downward displacement of the transducers should result in a measurement of the level of the fluid. Such a measurement is, however, encumbered with the draw-back that the coupling losses are not constant and make the measuring difficult.

Brief Description of the Invention
The object of the present invention is to provide a method of the above type and whereby the coupling losses are compensated for.

This object is according to the invention obtained by the distance between the transducers is substantially equal to a number of half wavelengths, and by the ratio of the signals received by the receiving transducer at various times being considered a measurement of the attenuation of the sound during the transmission.

When a pulse is transmitted from the transmitter, said pulse propagates along the horizontal path. The receiving transducer is arranged close to the transmitter and receives almost instantaneously a signal propagating in the container, and measures said signal influenced by the coupling losses. The same signal propagates around the container and hits the receiving transducer again, now one turn delayed and possibly attenuated due to the fluid. The same signal propagates also in the opposite direction and reaches the receiver at almost the same time. If these two signals are in counter-phase, they will outbalance one another. If the difference in the propagating paths corresponding to twice the distance between the transducers is a number of wavelengths, the signals are, however, received in phase. As a result, the distance between the transducers must be a number of half wavelengths, whereby the best possible signal-noise-ratios are obtained.

Moreover, the receiving transducer may according to the invention not be activated until in a time interval a predetermined period after activation of the transmitting transducer. As a result, the signal-noise-ratio can be further improved.

According to a particularly preferred embodiment, the time interval lasts approximately 50 ysec.

The invention relates also to an apparatus for measuring and indicating the fluid level in a container comprising at least two ultrasonic transducers which are arranged on the outer side of the container and which can be displaced up and downwards. The apparatus is characterised in that the distance between the transducers is substantially a number of half wavelengths. The resulting apparatus is particularly advantageous.

Brief Descrintion of the Drawings
The invention is explained in greater detail below with reference to the accompanying drawings, in which
Fig. 1 illustrates an apparatus according to the invention for measuring the fluid level in a container by means of ultrasound,
Figs. 2a and 2b illustrate a measuring head with two ultrasonic transducers for emitting and receiving, respectively, ultrasound,

Fig. 3 illustrates an associated electric circuit for processing the measuring signals,
Fig. 4 illustrates one of the ultrasonic transducers, and
Figs. 5 to 10 illustrate the measuring signal versus the position of the transducers at various fluid levels.

Best Mode for Carrying Out the Invention
A short sound pulse is transmitted into a container in form of a bottle by means of an ultrasonic transducer. The sound pulse propagates in all directions in the wall of the bottle and into a fluid optionally present in the bottle. As the bottle is a closed system, the same ultrasonic transducer can receive a spectrum of echoes from the previously emitted pulse. Now the strength and shape of the spectrum received renders it possible to decide whether the transducer is positioned above or below the fluid level in the bottle.

An up/downward displacement of the transducer renders it possible to determine the actual fluid level.

The sound can propagate in various manners in a solid matter: 1. By way of longitudinal oscillations whereby the solid matter
oscillates to and fro in the direction of propagation of the sound.

The speed of propagation in iron/steel is approximately 5,000 to 6,000 m/sec.

2. By way of transversal oscillations whereby the solid matter oscillates to and fro transverse to the direction of propagation of the sound wave. In the latter case, the solid matter is not concentrated in the transverse direction. The velocity of the sound is approximately 60% of the velocity of longitudinal waves.

3. Surface waves, i.e. waves only propagating in the surface of a solid matter. The velocity is approximately 90% of the velocity of transversal waves.

In fluids and gas only longitudinal waves can propagate.

A propagation of sound in a solid matter lasts until the losses have attenuated the sound, or until the energy has been transferred to another medium. The losses in solid matters are usually inversely proportional to the frequency. In contrast thereto, the losses are inversely proportional to the frequency in the second power in fluids. Other things being equal the latter means that the sound transferred from a solid matter to another has a tendency to be lost in the fluid. The coupling of sound from one medium to another is determined by the acoustic impedances of the two mediums.

If two solid matters have the same acoustic impedance, the sound wave can propagate freely from one solid matter to the other, also when the two solid matters differ considerably. The two solid matters must, however, be in complete contact with one another. If the acoustic impedances differ, a partial reflection takes place in such a manner that only some of the energy is transferred from one medium to the other, the excess energy being reflected.

The acoustic impedance is z = density the velocity of the sound, which as far as longitudinal waves are concerned corresponds to z = ff elasticity module density where the elasticity module corresponds to Young's module.

Thus a heavy and hard matter such as iron presents a high acoustic impedance, while a very light and easily compressible matter, such as a gas, presents a very low impedance. A high impedance is, however, not an expression of the sound wave having difficulty in propagating in the medium, nor of the losses being high in said medium, but an expression of how little the matter must move to and fro (the amplitude) in order to allow the wave to transmit a predetermined energy.

The impedance ratios of various classes of materials are:
Materials Relative impedance
Iron, brass, steel 100,000
Nylon, PVC, water, glycerine, silicone 10,000
Atmospheric air 1

ACOUSTIC RATIOS INSIDE THE BOTTLE

The signal from the ultrasonic transducer is a longitudinal wave. This wave is assumed to hit the wall of the bottle perpendicularly in a well-defined area of an extent being considerably shorter than the wavelength inside the bottle. At 200 kHz and 3,400 m/sec this wavelength is apprqximately 1.7 cm. The signal is emitted in pulses of 50 50 psec corresponding to approximately 10 oscillations.

Empty bottle

A wave propagates from the point of contact and along a circle inside the bottle. At first it is assumed that the bottle is empty and accordingly it is possible to disregard a propagation into the interior of said bottle. The type of propagation inside the approximately is probably transversal, and as the container wall of approximately 8 mm is of the same magnitude as the wavelength, the wave is as perceptible on the inner side as on the outer side of the bottle. If the bottle had an endlessly large surface, the radius of the circular propagation would be more and more increased until the signal became so weak that it could not be measured. The bottle presents, however, a closed surface. The signal is therefore attenuated in such a manner that it fills out the entire bottle.

When an ultrasonic transducer is placed an arbitrary place on the bottle, said ultrasonic transducer detects a complete series of copies of the signal transmitted. The first signal comes directly from the transmitter.Then signals appear which have travelled along the entire path around directly to the transducer twice. Other signals are reflected at the top or the bottom of the bottle and are therefore picked up by the transducer. When observed for a period of time, a few heavy signals appear at first whereafter a riot of comparatively weak signals appear for a relatively long period of time. The presence of these weak signals is caused by the signal inside the bottle not being attenuated, and these signals are referred to below as reverberation.

When the bottle is completely or partially filled with CO2 under pressure, different conditions apply. When the wave propagates correspondingly in the bottle material, the inner side of said bottle oscillates out and inwards relative to the interior of said bottle. As long as the interior is only filled with air/gas, this movement cannot transfer any energy of significance to the air. The latter is obvious from the acoustic impedance of air not differing considerably from the impedance of the bottle material. The acoustic impedance of non-condensed CO2 at 50 atmospheres is relatively low.It is a different matter when CO2 is in fluid form. Fluid has typically an impedance of 1/10 of the impedance of metal with the result that energy is transferred from the metal wall to the fluid. As CO2 fluid apparently suffers from high losses at the frequency used, this energy is converted into heat and disappears accordingly from the acoustic image. The more the wave propagates in the bottle with fluid on the inner side, the more energy is lost.

A direct signal from the transmitter to the receiver is therefore attenuated more when fluid is present along the signal path instead of air.

In addition, the reverberation sound is less both with respect to amplitude and duration when two transducers are arranged below the fluid level. The reverberation is strongest when the transducers are arranged above the fluid level. The total reverberation is, however, reduced when the fluid level in the bottle is increased.

Below the measuring principle is described.For the sake of simplicity, the balancing of the variable contact between the transducer and the bottle by means of an extra transducer has been omitted here. Thus the description is based on the fact that the same transducer is used alternately as a transmitter and a receiver, as well as that the coupling to the bottle is always the same.

Two different detection methods are used:

Directly: The attenuation of the first direct signal being received. This signal has travelled exactly one time around along a circular path perpendicular to the vertical axis of the bottle.

Space sound: Measuring of noise in a time window of 1 to 5 msec. after the transmission of an ultrasonic pulse.

Advantages and draw-backs apply to both methods. The direct method provides a well-defined signal, as

the travelling time and consequently the attenuation of the signal is constant across the entire cylindrical portion of the bottle. The draw-back is, however, that the ratio of the signal above to the signal below the fluid level is approximately 3:2 corresponding to an attenuation of no more than approximately 50%. Furthermore, the requirement to a well-defined signal is not met in the uppermost and lowermost portion of the bottle due to reflections from shoulder/bottom.

With respect to time these reflections appear to interfere with the desired signal.

The reverberation method turned out to be efficient when the fluid level is in the uppermost portion of the bottle. If the fluid level is very low, it can be difficult to determine said fluid level due to false signal transitions which are almost as specific as the actual signals. Accordingly, nothing but a few vague echoes are available for the measuring and not a well-defined signal. When the measuring is performed above the fluid level, strong and weak areas apply in which echoes from the shoulder interfere with signals having travelled along the entire path several times. A proviso for signals in the reverberation window is that echoes apply which travel several times along the entire path above the fluid surface before they are measured. When the measuring is performed below the fluid level, the reverberation is usually very low, but when the fluid level is low non-attenuated reflections from the shoulder can penetrate below the fluid level and cause false measurings.

When the fluid level is too high, surviving echoes travel in paths almost perpendicular to the axis of the bottle. Accordingly, they cannot penetrate below the fluid level and cause false measurings.

By adjusting the positioning of the time window it is possible to compensate for some of these problems, and especially the reverberation measuring can indicate whether the container is completely or almost empty.

Both measurements have revealed that it is always possible to see a possible fluid transition. The problem is how the false transitions are removed.

By a measuring, the bottle is divided into three sections.

An upper section: From the shoulders of the bottle and approximately a shoulder diameter downwards.

The measuring is exclusively performed by means of reverberation because the direct measuring is destroyed by shoulder reflections,
An intermediary section: The area between the upper and the lower section. The measuring is primarily a direct measuring strongly supported by reverberation in such a manner that a fluid transition must be detectable during both measurings in order to be accepted.

A lower section: From the bottom of the bottle and approxi imately 1 bottle diameter upwards. Only little experience applies to this area. It is probably only possible to indicate whether the level is low/the bottle is empty.

The transmitting/receiving surface of the ultrasonic transducer is composed of high-impedance material. A proviso for allowing a transfer of the energy between the bottle and the transducer is that the contact is good. In general, the curvature of the bottle and the roughness of the surface coating result in a relatively poor contact. The contact area is mainly composed of air having a very low impedance. Furthermore, the reproducibility of the contact is poor when the transducer is moved up and down along the bottle. A good contact means that a strong pulse is emitted into the bottle with the result that strong echoes arise. A good contact means furthermore that the receiving transducer measures signals inside the bottle to a wide extent, i.e. possible errors caused by the coupling are amplified.

Two methods apply for solving this problem. Firstly, a mechanical, soft coupling medium of a suitable acoustic impedance must be provided between the transducer and the bottle. This medium can for instance be a fluid. Such a fluid is, however, inconvenient both because it is consumed and because it pollutes the bottle. Therefore a solid silicon rubber presents an improved contact material, cf. Fig. 2. Such a material requires, however, a predetermined pressure in order to fill out possible unevennesses in the contact area.

The extent of the pressure area must not exceed half a wavelength of the sound in the bottle, and max. 8 mm. A diameter of 4 mm is a good compromise between a large coupling surface and a requirement for a high contact pressure in such a manner that unevennesses in the surface of the bottle are filled out.

The second method is to compensate completely for the losses in the contact. Then the transmitting/receiving transducer is divided into a transmitting transducer and a receiving transducer. These transducers are arranged close to one another in a plane perpendicular to the vertical axis of the container, cf. Fig. 2. Then a pulse from the transmitter propagates along a circular path like previously. The receiver is arranged close to the transmitter and receives almost instantaneously a signal propagating in the container, and measures said signal subjected to said coupling losses. The same signal continues around the container and hits the receiving transducer again, now one turn delayed and attenuated due to the propagation and possible fluid. This signal is again measured by the receiver, said signal being subjected to the same coupling losses. The ratio of the two signals presents then a true measurement of the signal attenuation around along the bottle, and this ratio is independent of the coupling losses of the transmitter and the receiver. This method is conditioned by the following: 1. The receiver receives a signal having propagated from the left to the right, and a signal having propagated from the right to the left from the transmitter. These two signals are added up. The reference sig nal is, however, only received from for instance the left side of the transmitter. If the transmitter and/or the receiver are directioned, i.e.

their transmitting/receiving is improved in specific directions, this will have no effect on the compensation. The latter may, however, have an effect if the direction is changed in connection with a testing on various locations of the bottle.

2. The receiver receives two signals almost simultaneously from the transmitter. One signal from the left to the right and one signal from the right to the left. As the signals do not follow the same path of propagation (the left signal propagating one turn around the bottle plus the distance between the transmitter and the receiver while the left signal propagates one turn around the bottle minus said dist ance between the transmitter and the receiver), it must be ensured that the two signals are received in phase. If they are received in counterphase they extinguish one another. The difference in the path of propagation is twice the distance between the contact locations for the transmitter and the receiver, respectively. A proviso for placing the signals in phase is that the double distance must be a number of the wavelength of the sound inside the bottle.

When the various bottles present different sound velocities, it is therefore necessary to mechanically adjust the measuring head. As long as the bottles are made of the same material, the velocity is constant.

The thickness of a layer of paint, if any, on the bottle forms part of the coupling resistance too. The effect of a thick layer of paint can also be compensated for.

Figs. 2a and 2a illustrate the measuring head arranged at the end of an arm 2 connected to a manually operated bar 4. This bar 4 renders it possible to move the measuring head 6 towards the surface of a bottle 8 and up and down along said bottle. The measuring head 6 comprises a block 10 housing two transducers 11, 12, a transmitter, and a receiver.

The transducers 11, 1 2 are biased by means of springs 1 4 in such a manner that they are pressed against the bottle by a well-defined force.

The block 10 comprises four projecting supporting legs 1 6 for determining the position of the block 10 relative to the curvature of the bottle. The transducer 11, 1 2 then adjusts to the curvature. In order to position the transducers 11, 1 2 substantially perpendicular to the surface of the bottle 8, they present an angle of approximately 30. When the measuring head 10 is pressed against the surface of the bottle, the block 10 adjusts in a specific manner whereby possible angular differences are absorbed by two pivot joints. These two pivot joints are formed by a turning shaft 18 in the middle of the block 10 and connected to the transverse arm 2, as well as of some bearings 20 associated with said transverse arm 2. When the transverse arm 2 is not completely horizontal, the supporting legs 1 6 cannot contact the curved surface of the bottle in a correct manner. A spirit level can optionally be provided for ensuring the horizontal position of the transverse arm. Such an arrangement renders it possible to examine a large number of bottles 8 arranged behind one another, because the measuring head 10 can be moved from one bottle to another.

A suitable electronic test equipment is provided, cf. Fig. 3. The transmitting unit comprises a 200 kHz oscillator 30 being activated by means of a timer for approximately 50 jisec. for every 5 msec. The oscillator signal is emitted to an output amplifier 32 driving the transmitter transducer. The receiving unit comprises an input buffer 34 followed by an amplifier 35 with AGC. The amplitude of the strongest received signal, i.e.

the reference signal directly from the transmitter, is measured on the output of the amplifier, and the amplification is adjusted by means of a feedback in such a manner that said signal receives a constant amplitude.

Other signals can subsequently be considered independent of the coupling.

After the amplification, the signals for the Direct and reverberation circuits are transmitted to an oscilloscope. In the Direct and reverberation circuits, the signals are further amplified and rectified. The time interval of interest is detected by means of an electronic contact. The detected signal is integrated at 38 and read by means of a voltmeter. A 50 jisec. signal is selected for the direct signal approximately 270 jisec. after the transmission of the pulse. A 2 msec. signal is selected for a reverberation signal 2.5 msec. after the transmission of pulse.

Figs. 5 to 10 illustrate examples of the measuring results.

Bottle 1 (Fig. 5): Both the Direct and the reverberation method show a clear transition at 55 cm. A radioactive measuring indicates a transition at 52 cm.

Bottle 2 (Fig. 6): A false jump at approximately 50 cm is located by means of the Direct method, but not by the reverberation measuring. At approximately 110 cm both methods reveal a fluid transition. A radioactive measuring indicates 105 cm.

Bottle 3 (Fig 7): The reverberation method reveals a transition at approximately 62 cm. A radioactive measuring indicates a transition at 60.5 cm.

Bottle 4 (Fig. 8): Test of the fluid level 14 cm from the shoulder. The reverberation measuring reveals a transition at 142 cm. A radioactive measuring indicates a transition at 140 cm.

Bottle 5 (Fig. 9): Test of the fluid level 11 cm from the shoulder. On the face of it, no transition exists by a reverberation measuring. A more detailed analysis reveals, however, that the reverberation transition can be identified

provided the window is displaced in such a manner that it starts 1 msec. after the transmission of the pulse.

Bottle 6: Test of measuring 5 cm from the shoulder. No reverberation effect applies, not even when the window is displaced.

Bottle 7 (Fig. 10): The reverberation method reveals a transition at approximately 11 5 cm, which corresponds to the direct method when said method is analysed on the oscilloscope.

The purpose of using the transducer as transmitter is to convert an electric oscillation into a mechanical oscillation, and the purpose of using said transducer as receiver is to convert a mechanical oscillation into an electric signal. The transducer comprises a ceramic material with electrodes coated thereon. The ceramics is piezo-electric and provided with a bias stress in one of its dimensions. This bias stress compresses the material whereby a mechanical stress arises. An electric field parallel to said mechanical stress either intensifies or weakens this stress, and as the ceramics is deformable, the dimensions are changed correspondingly. Accordingly, an electric stress variation results in a corresponding mechanical variation.

On the other hand, a mechanical pressure reduces the distance between the end surfaces and consequently between the electrodes. As the electrodes and the intermediary ceramics form a capacitor of a capacity being inversely proportional to the distance between the electrodes, the value of said capacitor is changed correspondingly. Accordingly a constant charge results in a change in the stress across the electrodes.

The ceramic elements are shaped as disks of a thickness of approximately 2 mm and a diameter of approximately 10 mm. A silver electrode is coated on each side of the disk. Such an element possesses two types of resonances.

1. Thickness resonance at a frequency of a wavelength of twice the thickness of the disk.

2. Width resonance at a frequency of a wavelength of twice the diameter of the disk.

A PZ27 disk of 2 10 mm results in a thickness resonance of 1.1 MHz and a width resonance of 200 kHz. The ceramic disk is arranged at the end of a closed metal tube. The inner conductor of the connecting lead is soldered to the inner side of the disk. The outer conductor is connected to the metal tube and to the outermost electrode of the disk. In this manner the noise-sensitive inner conductor is screened. In order to allow release of energy from the outer side, the inner side of the disk must be placed on a material, such as an epoxy material of a suitable acoustic impedance at the same time as the ceramics is allowed to oscillate freely.

Below an example of an embodiment of an apparatus according to the invention and its operation is explained in detail.

Fig.1 is a front view of of the apparatus. At the top the apparatus is provided with an LCD display with two lines of 1 6 characters. The display must guide the user and display the measuring results during the measuring.

Two fields with buttons are provided. The upper buttons OK and START are used during the measurement. The lower button is used for the setting etc.

A bottle is shown to the left. This bottle comprises 5 light-emitting diodes positioned at different heights. These light-emitting diodes serve to indicate the area being measured. The apparatus is intended for right hand operation. The left hand handles the measuring head and the transducers.

During an ordinary measuring procedure nothing but OK and START are to be used.

The apparatus is switched on/off by means of the ON/OFF button. A measuring sequence is initiated by pressing on START. Then the lowermost light-emitting diode emits light which indicates that a measuring is to be performed at the height in question. The light-emitting diode continues to emit light until the apparatus registers that the measuring head is in contact and an acceptable measuring signal has been received.

When the measuring head is in the desired position and when the light-emitting diode emits light constantly, the OK-button is pressed down.

Subsequently, the apparatus receives a number of direct measurings and reverberation measurings for this measuring position. Then the lowermost, but one light-emitting diode emits light and the procedure is repeated for all five levels.

After OK at the uppermost light-emitting diode, the apparatus calculates the most probable interval for the fluid level, and the two light-emitting diodes around said level are activated. When the bottle is considered to be empty, only the lowermost diode emits light, and when the fluid level is above the uppermost light-emitting diode, nothing but said uppermost light-emitting diode emits light. Now the apparatus is to be manually operated. The uppermost line of the display indicates the measurings for
Direct, and the lowermost line indicates the measuring for reverberation.

To the right of the lines, the measuring results are indicated in absolute numbers. To the left, a horizontal column is shown. Based on the five reference measurings, the apparatus calculates the expected value of the fluid level. The column has been set such that this value is close to the character No. 6, which has been indicated by means of an arrow and
LEVEL. In this manner the apparatus indicates the position of the expected fluid transition, as well as the desired measurings. The measuring head can be moved up and down until the desired transition has been located. Like previously, the light-emitting diodes do not emit light constantly until the measuring signal is correct. When the level has been located, the procedure is continued with the next bottle by pressing on START.

Claims

1. A method of measuring and indicating the fluid level in a preferably cylindrical container comprising at least two ultrasonic transducers (11, 12), which are arranged on the outer side of the container and preferably along a horizontal path, and which can be up and downwardly displaced, c h a r a c t e r i s e d in that the distance between the transducers (11, 12) substantially corresponds to a number of half wavelengths, and that the ratio of the signals received by the receiving transducer at various times is used as a measurement of how much the sound has been attenuated during the transmission.

2. A method according to claim 1, c h a r a c t e r i s e d in that the receiving transducer is not activated until in a time interval following a predetermined time after the activation of the transmitting transducer.

3. A method according to claim 2, c h a r a c t e r i s e d in that said time interval is approximately 50 jisec.

4. A method according to claims 1 to 3, c h a r a c t e r i s e d by further measuring the reverberation signal versus the position of the transducer.

5. A method as claimed in one or more of the preceding claims, c h a ra c t e r i s e d by utilizing especially the changes in the reverberation signal versus the position of the transducers for measuring high fluid levels.

6. A method as claimed in claim 5, c h a r a c t e r i s e d by the reverberation signal being measured approximately 1 to 5 msec. after transmission of the ultrasonic pulse.

7. A apparatus for measuring and indicating the fluid level in a preferably cylindrical container comprising at least two ultrasonic transducers (11, 12), which are arranged on the outer side of the container and preferably along a horizontal path, and which can be up and downwardly displaced, c h a r a c t e r i s e d in that the distance between the transducers (11, 12) is substantially a number of half wavelengths.

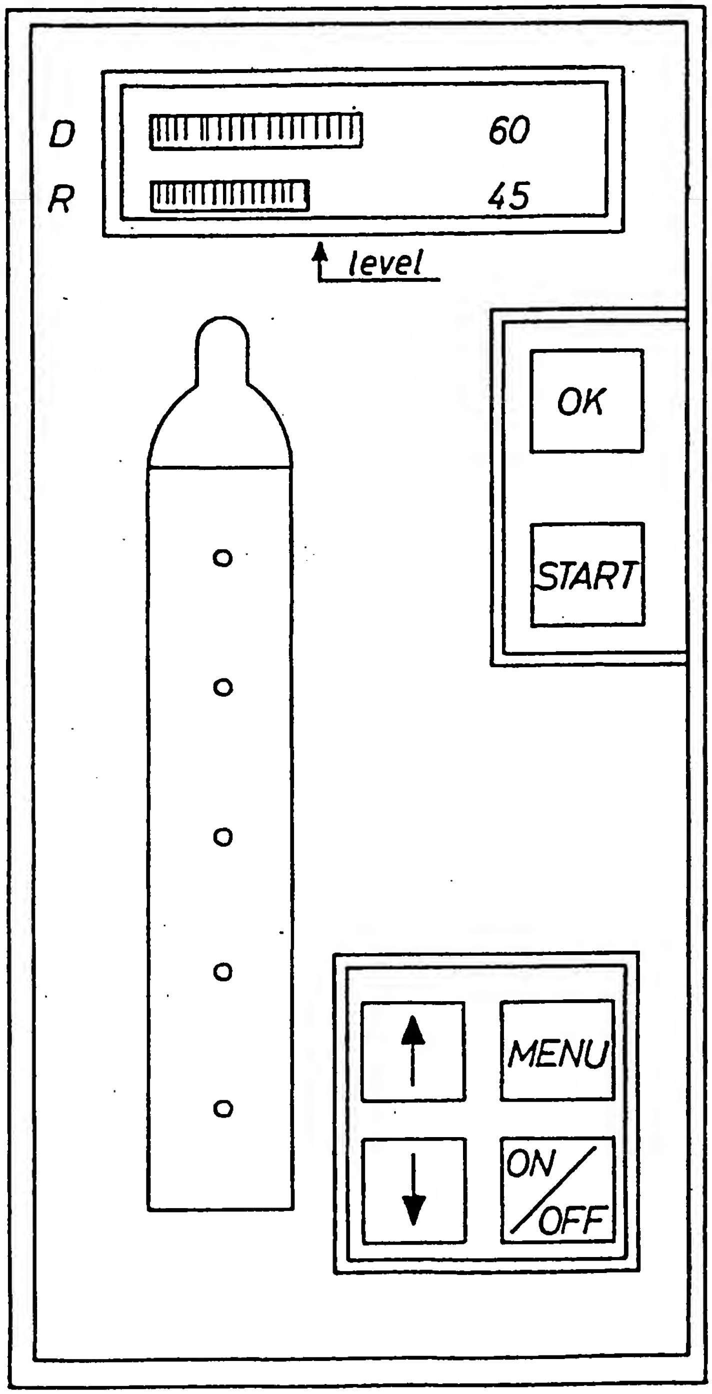


Fig. 1

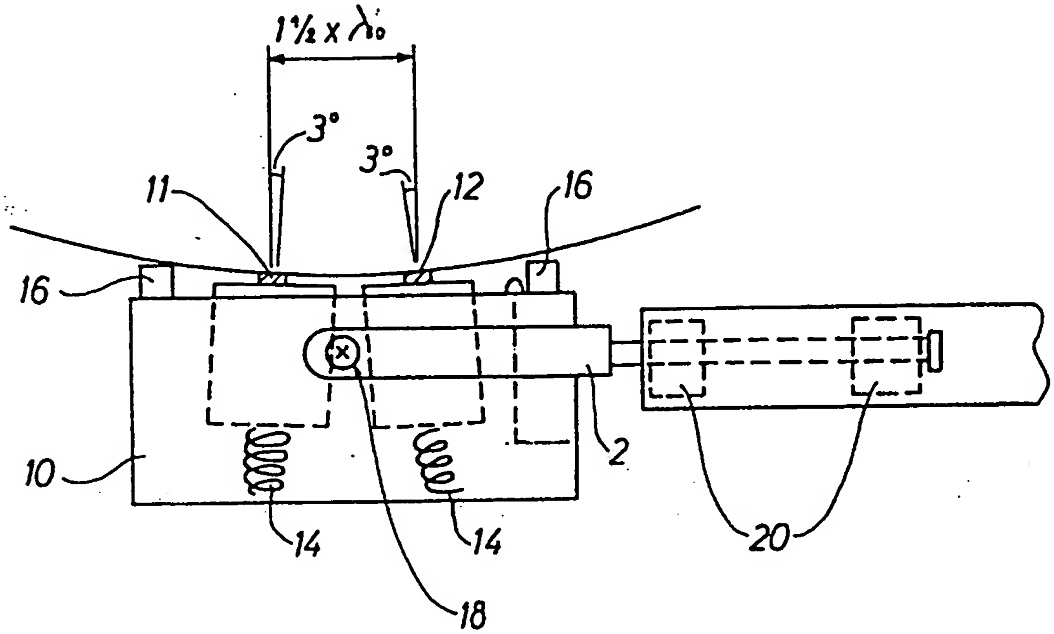


Fig. 2a

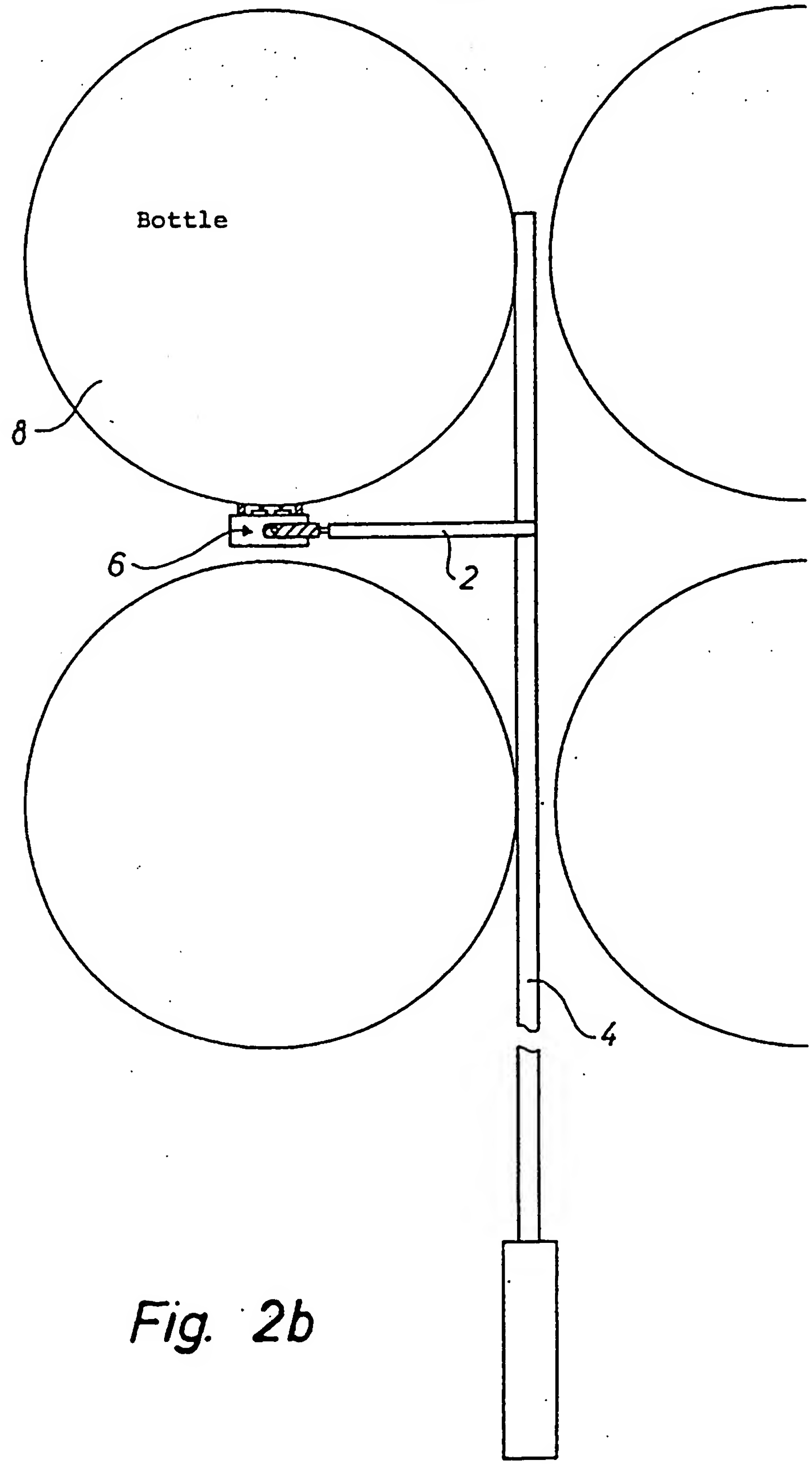
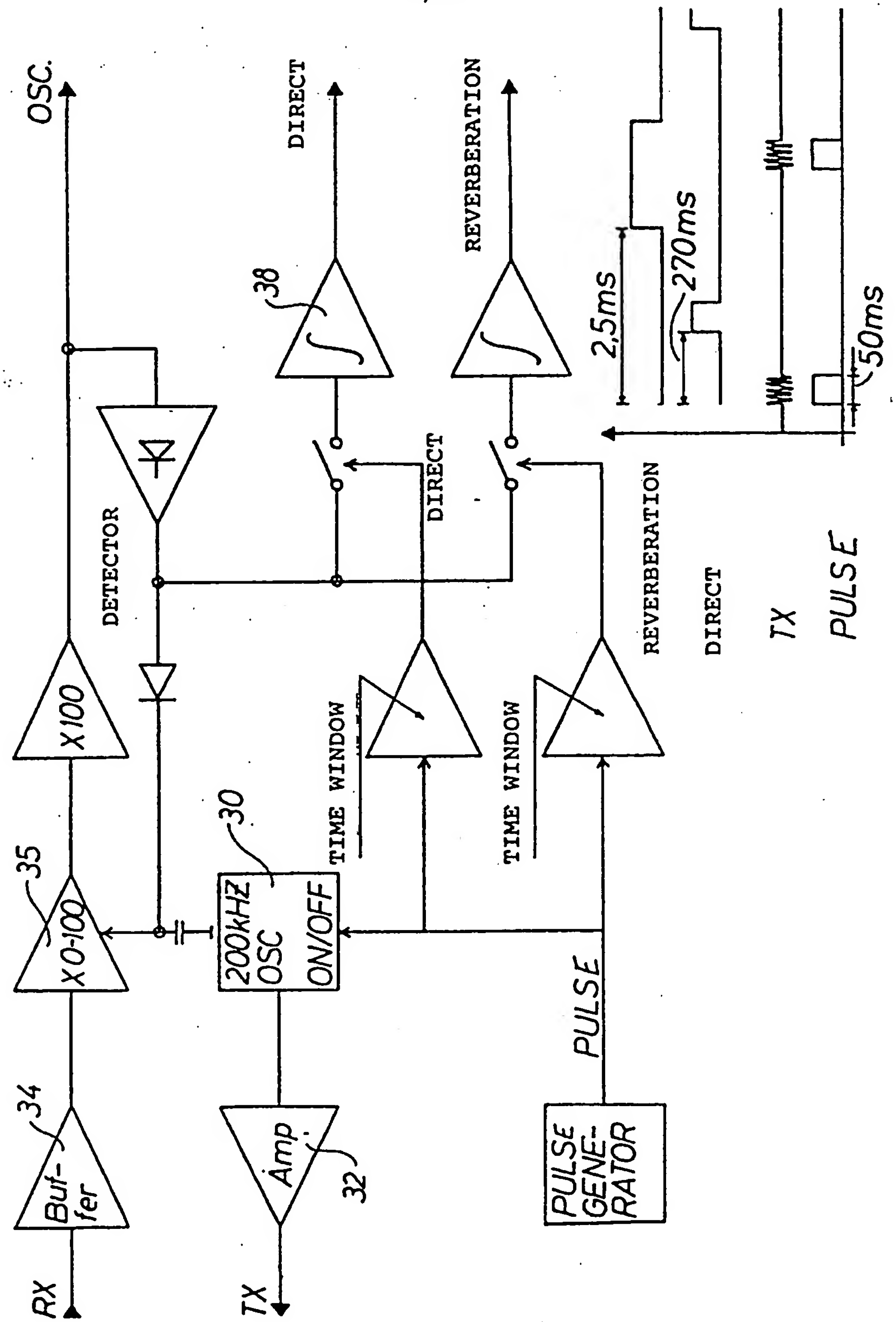


Fig. 2b



OSC.
DIRECT
REVERBERATION
38
DETECTOR
DIRECT
REVERBERATION
X100
35
X0-100
30
200kHz OSC ON/OFF
TIME WINDOW
TIME WINDOW
34
Buf-fer
Amp
32
PULSE
PULSE GENE-RATOR
RX
TX
2,5ms
270ms
50ms
REVERBERATION
DIRECT
TX
PULSE

Fig. 3

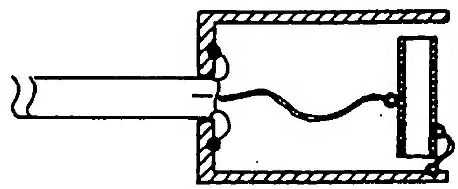


Fig. 4

HEIGHT (TO SHOULDER) : 135 cm
Diameter : ≈21 cm

CHARACTERISTICS: RUSTY SURFACE

RADIOACTIVE MEASURING: 52 cm

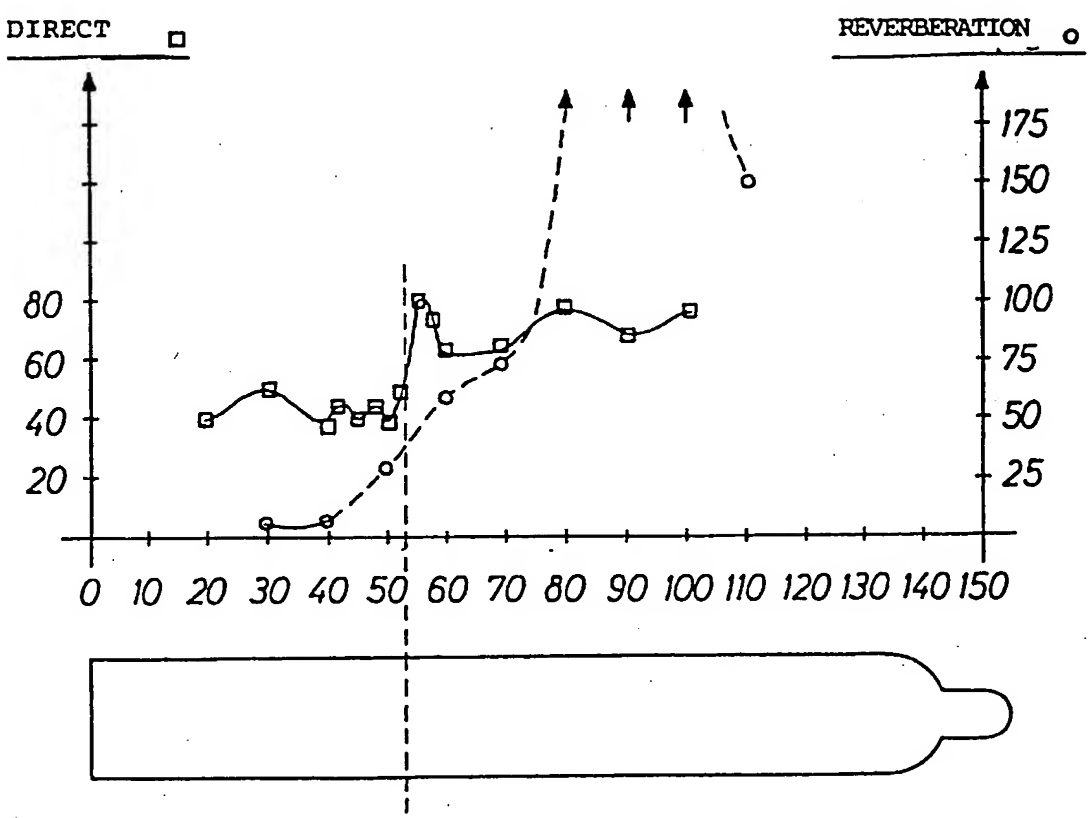


Fig. 5

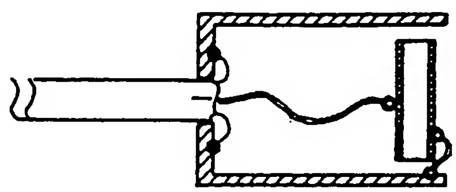


Fig. 4

HEIGHT (TO SHOULDER) : 135 cm

Diameter : ≈21 cm

CHARACTERISTICS: RUSTY SURFACE

RADIOACTIVE MEASURING: 52 cm

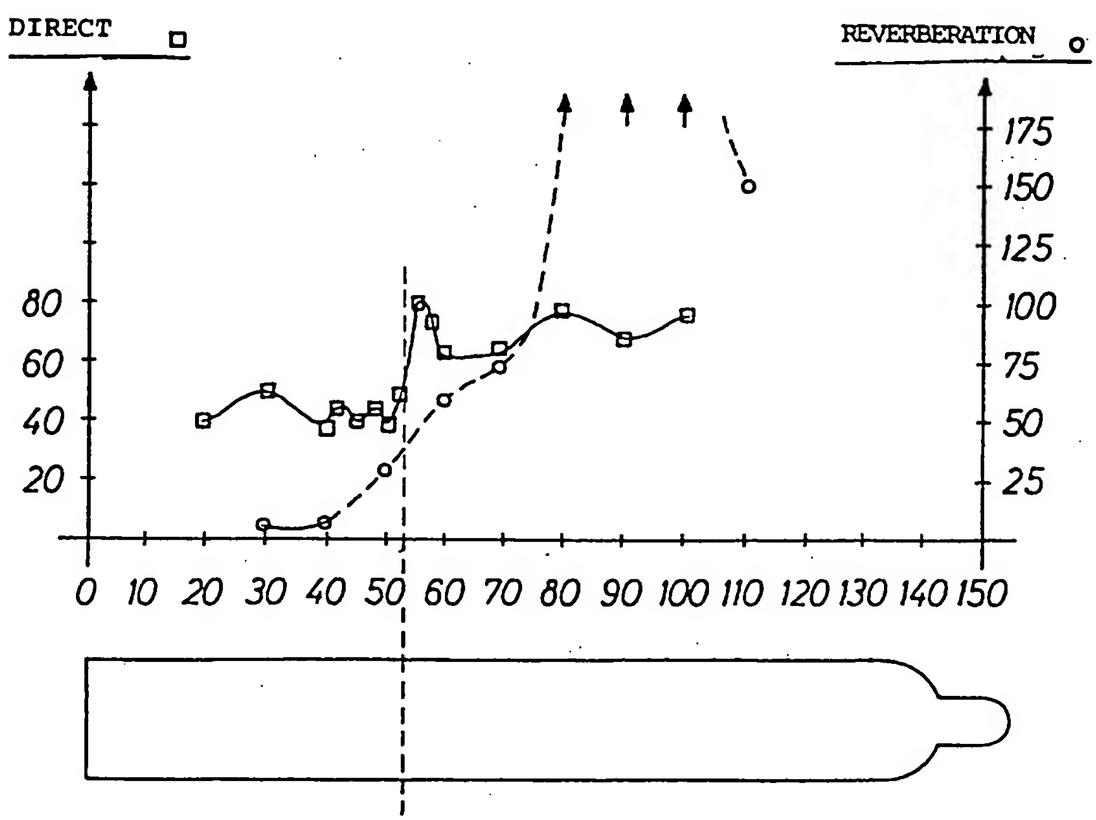


Fig. 5

VOLUME : 46,5 kg

HEIGHT (SHOULDERS) : 140 cm

Diameter : 21 cm

RADIOACTIVE MEASURING : 105

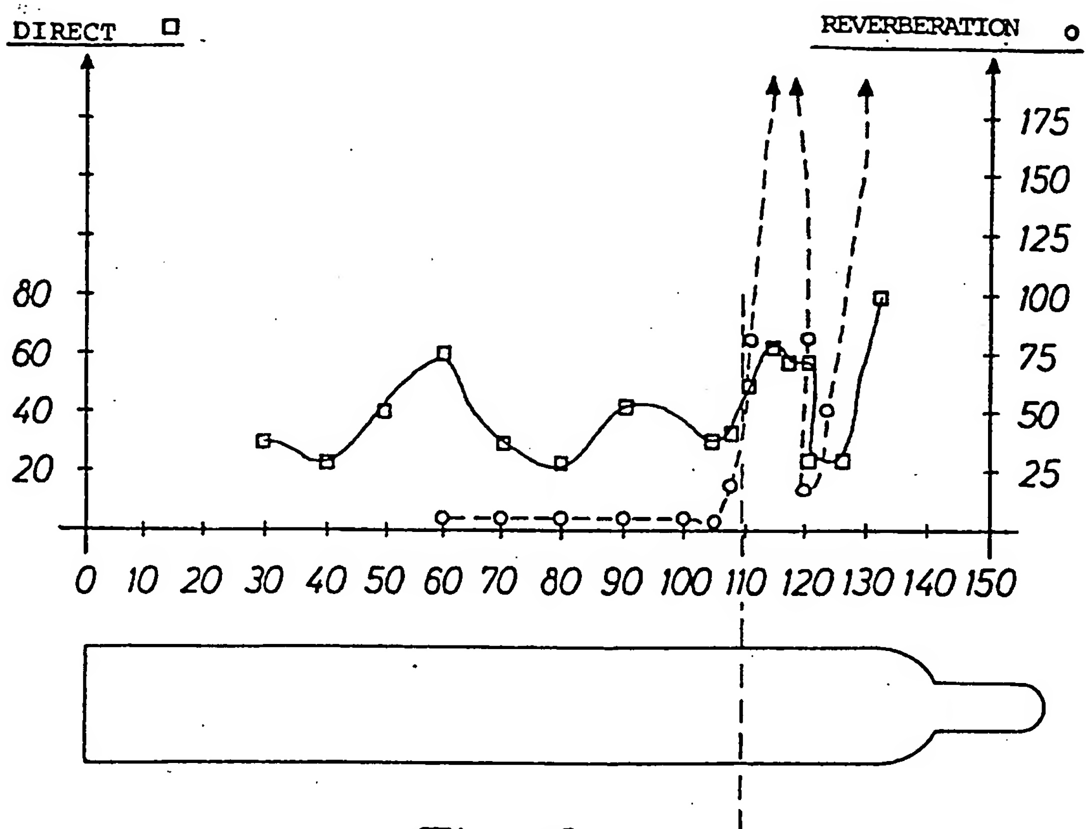


Fig. 6

VOLUME : 6 kg
HEIGHT (TO SHOULDERS): 72
Diameter :

CHARACTERISTICS: Small bottle

RADIOACTIVE MEASURING: 60,5

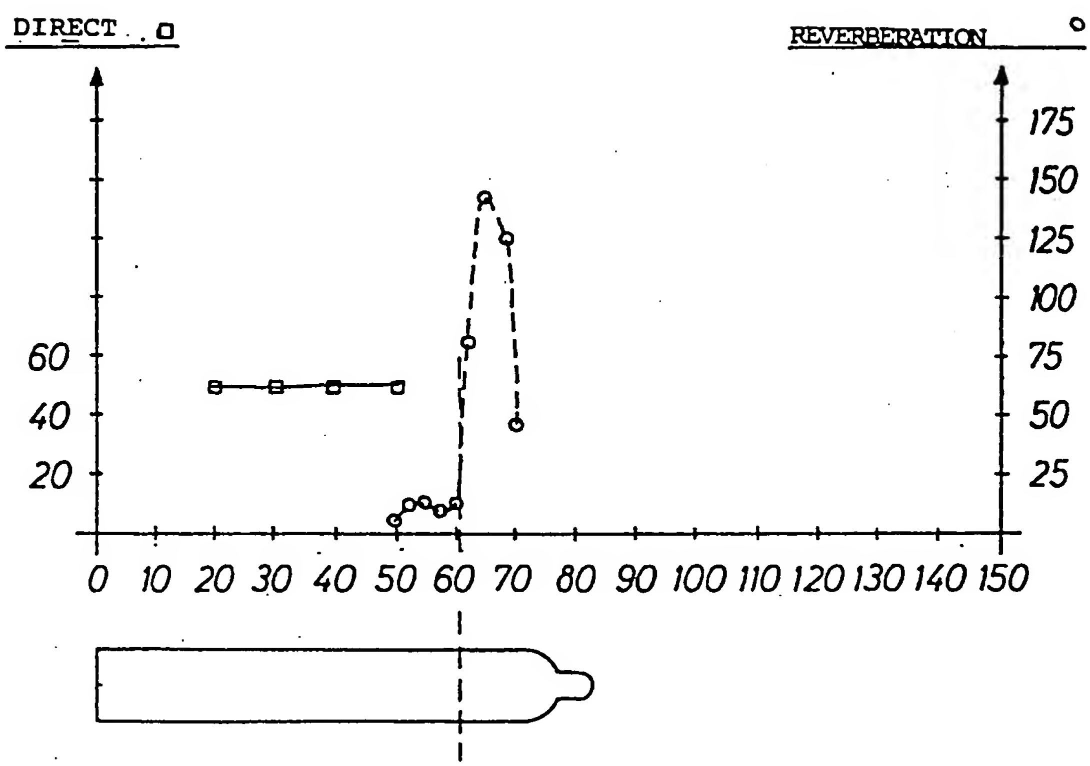


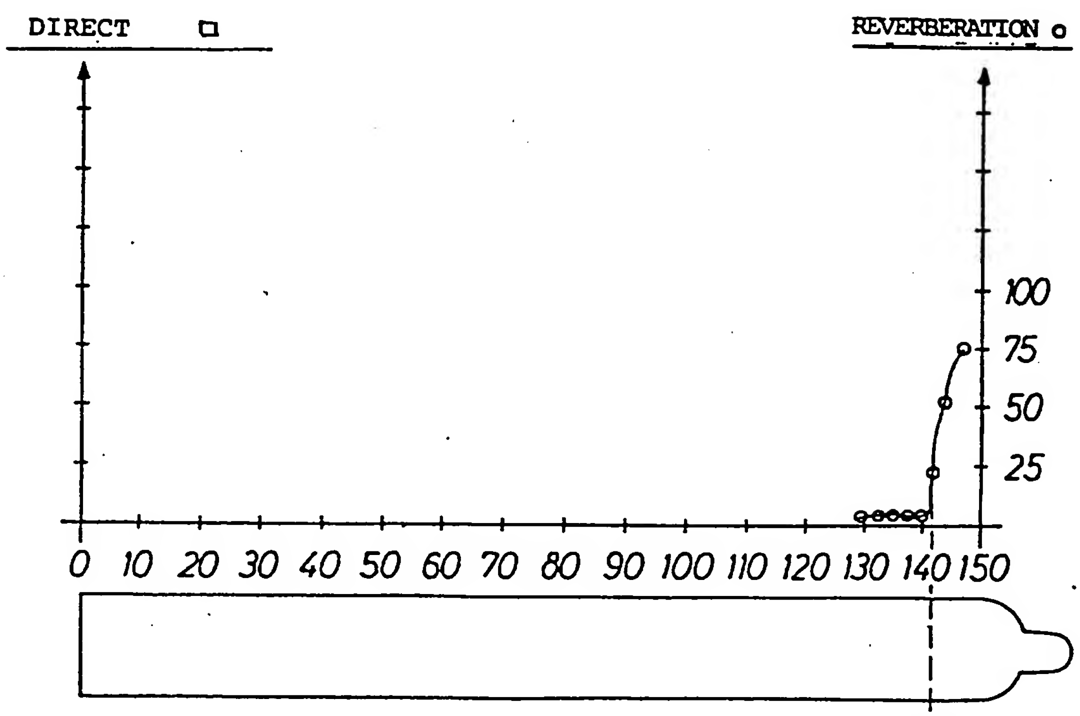
Fig. 7

HEIGHT (TO SHOULDERS) 154

Diameter : ___

CHARACTERISTICS: Level 14 cm from the shoulders

RADIOACTIVE MEASURING : 140



COMPLETELY FULL FROM THE START: REVERBERATION x 0 ALL THE WAY UP THEN THE BOTTLE WAS EMPTIED TO 140 cm.

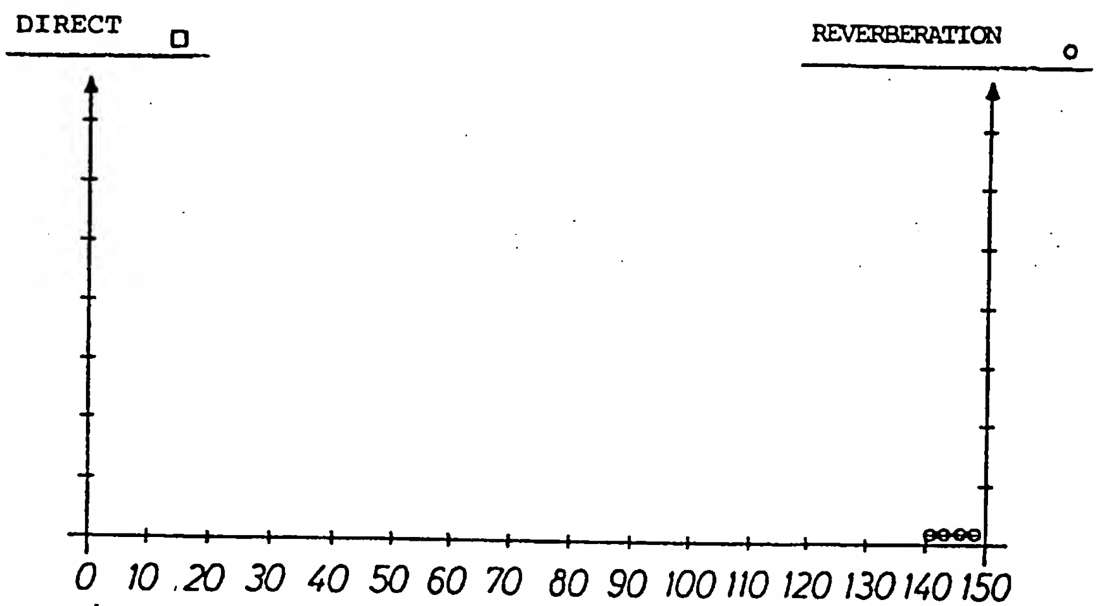
Fig. 8

HEIGHT (TO SHOULDERS) : 154

Diameter :

LEVEL 11 cm FROM SHOULDERS

RADIOACTIVE MEASURING: 143



REVERBERATION ONLY PRESENT DURING THE 2.5 ms → NO SIGNAL

CLEAR CHANGE IN REVERBERATION DURING THE TIME INTERVAL 1 → 2,5 ms.

Fig. 9

VOLUME: : 67,5l

HEIGHT (TO SHOULDERS): 130

Diameter : 27

CHARACTERISTICS: THICK LAYER OF PAINT

RADIOACTIVE MEASURING:

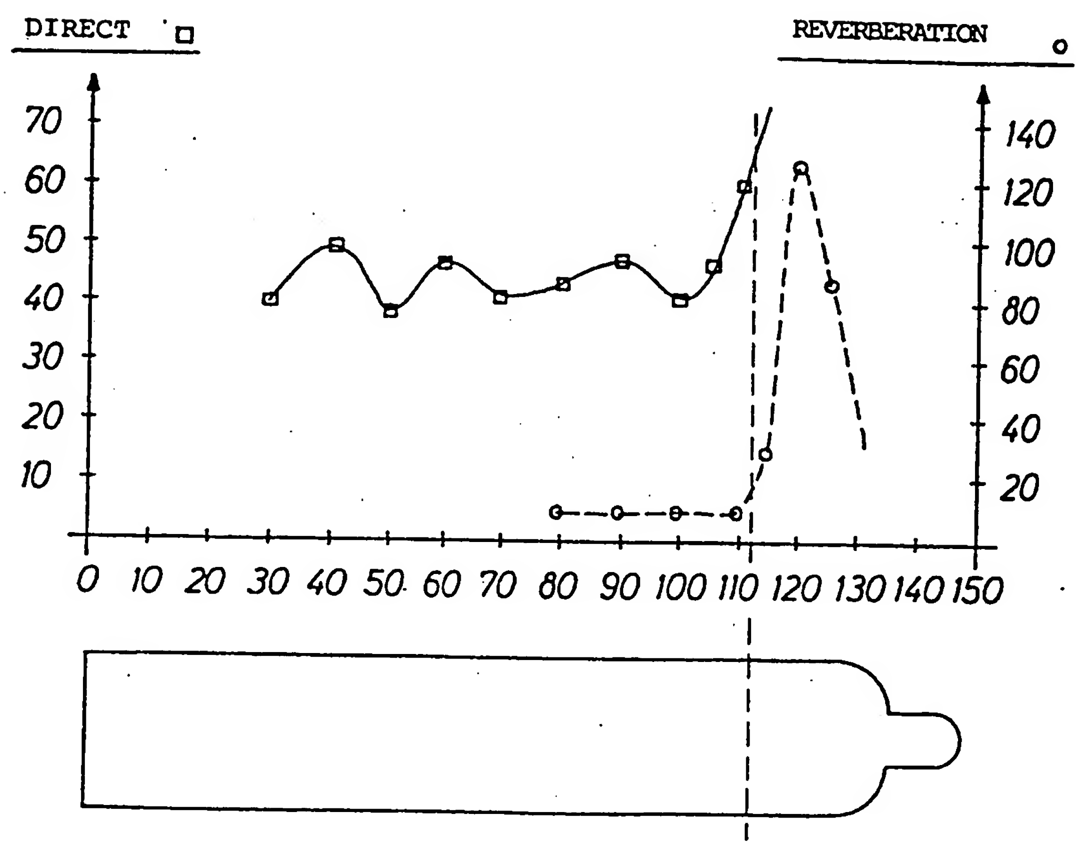


Fig. 10